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COST SENSITIVITY ANALYSIS

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The RAND Corporation's Cost Analysis Department has for the last 12 years provided many answers concerning the economic impact, 5, 10, or 15 years into the future, of alternative military plans. Inevitably involved in these alternative plans has been uncertainty, in varying degrees and taking many forms. For example, there is always uncertainty involved in predicting a future threat, uncertainty as to the origin, time, and extent of the threat -- but threat analysis is nonetheless fundamental to military planning. There is also uncertainty associated with the design of a weapon system to meet a threat with regard to equipment performance, reliability, and operations. Finally, there is uncertainty associated with the ability of the cost analyst to translate the design of the weapon system into a statement of resource requirements and costs.

In this presentation I shall try to show that cost sensitivity analysis can provide a meaningful method for handling uncertainty. I shall also attempt to show that cost sensitivity analysis can be used to compare alternative weapons configuration and operational plans.

Broadly, cost sensitivity analysis is the process of determining how variations in the configuration of a weapon system affect the weapon system resource requirement or cost. This is accomplished by varying the major design and operational parameters over their relevant

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ranges one at a time and then measuring and presenting the effect of each change upon the total system cost.

In order to demonstrate how cost sensitivity analysis is performed, I have prepared an illustration using one weapon system and its cost.

This illustration begins by hypothesizing a requirement to protect the continental United States against a threat of a submarine-launched ballistic missile attack. We can assume that only meager information exists concerning the kind and number of submarines and missiles that would make up the threat. We must therefore deduce the tactical options* available to a potential enemy by using the operations of our own submarine fleet as a basis.

Chart 1 is a map of the continental United States; the shaded area extends approximately 1000 miles from either shore. As an initial step toward designing a system, we will assume that the mission will be to provide defense against SLEMs (and the submarines that carry them) in this shaded area. As we progress we will examine, among other things, the sensitivity of costs to this important assumption.

We want to investigate the use of a manned aircraft, functioning as a continuously airborne missile-launching platform, as the central component of the system for performing this mission. The payload of the aircraft will consist of various combinations of missiles and electronics equipment, one of which is illustrated in Chart 2. Once the radar aboard the airborne platform detects an SLEM, the air-launched missiles will intercept it during the boost phase of its trajectory (boost intercept). Chart 3 illustrates one variation of this system. In this case, the air-launched missile intercepts the SLEM after cut-off and during the mid-course phase of its trajectory. Chart 4 illustrates another variation, a counter-battery capability. Here, the fact that a missile has been launched from a submarine is observed on the aircraft radar, but, rather than attempting to

*These tactical options would be based upon an estimate of the capability of our passive detection systems to detect and localize enemy submarines.

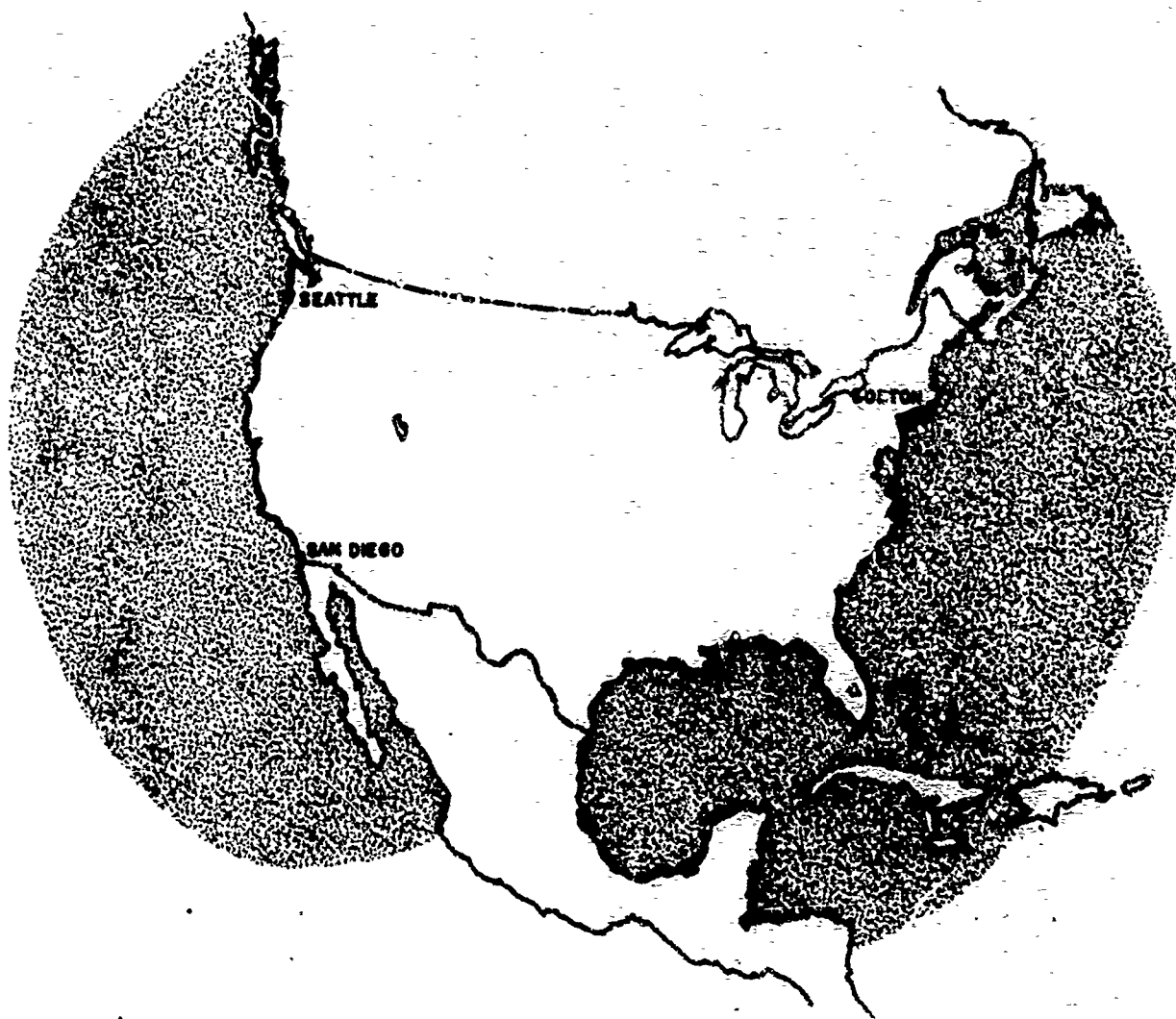


Chart 1—Defense zone
(1000 n mi out from both coasts)

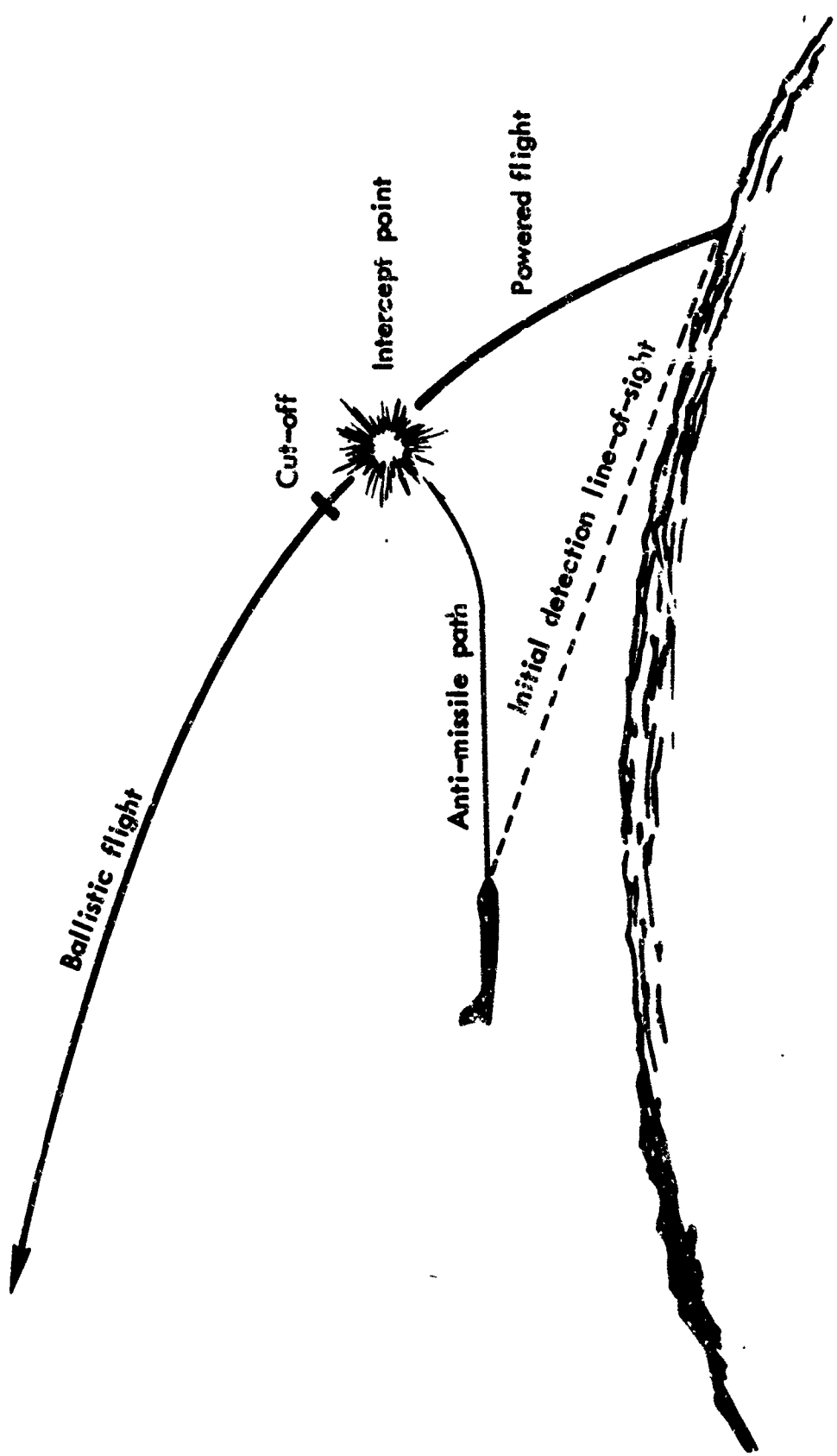


Chart 2—Boost-intercept

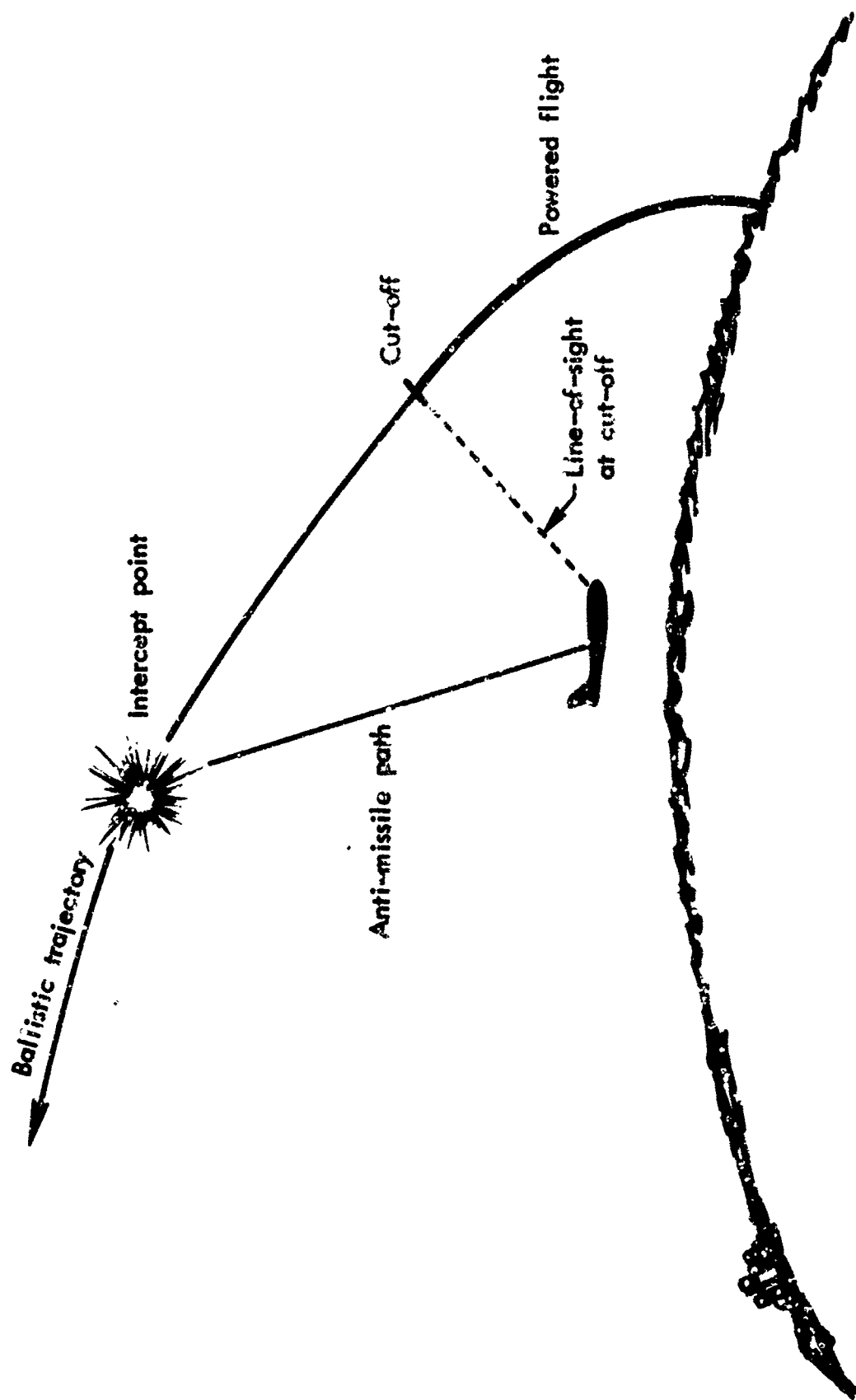


Chart 3—Mid-course intercept

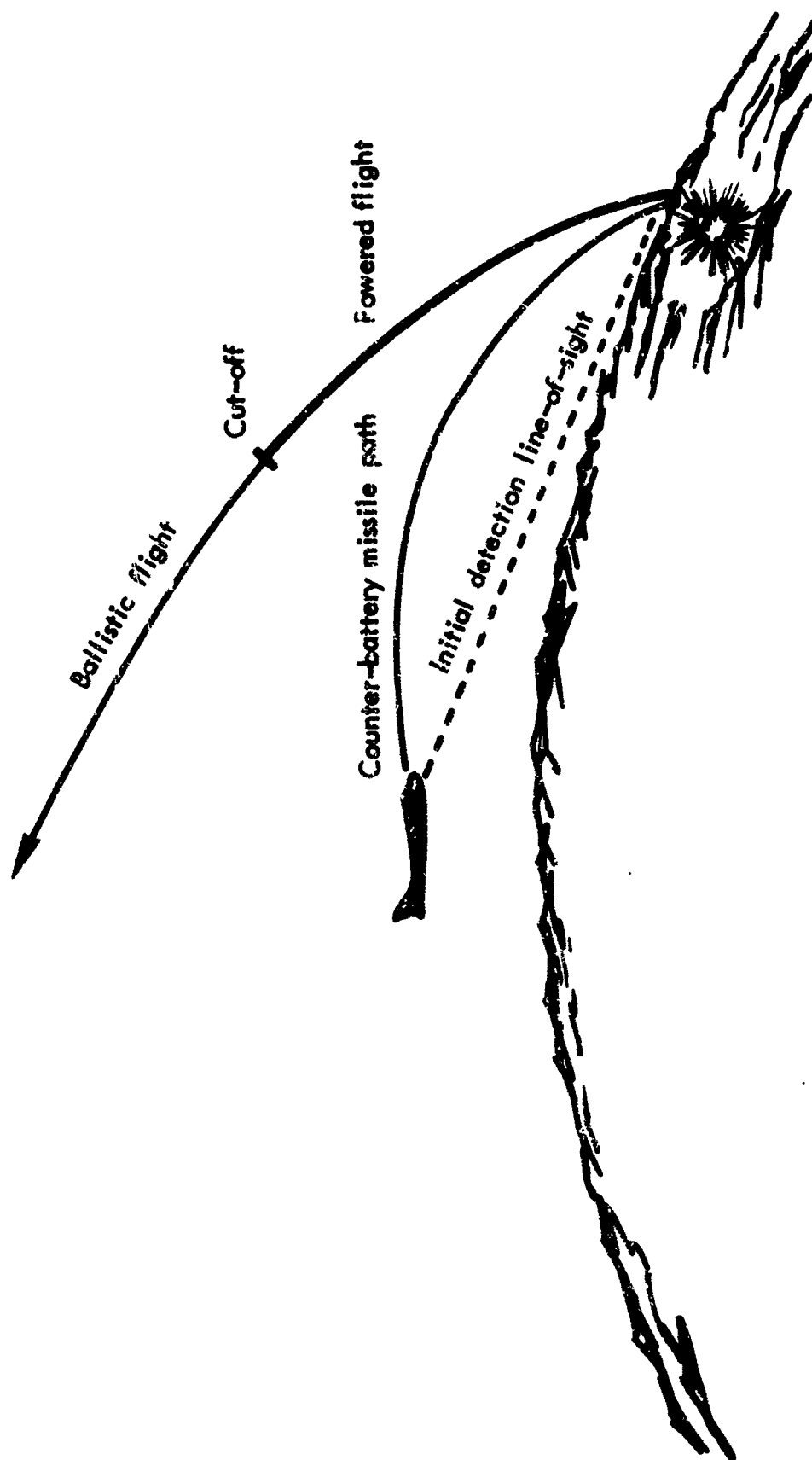


Chart 4--Counter-battery

intercept the missile itself, it directs its attack against the launching submarine. For our purposes today, we can assume a weapons capability which includes both terminal defense against the SLEM (boost intercept) and the submarine (counter battery).

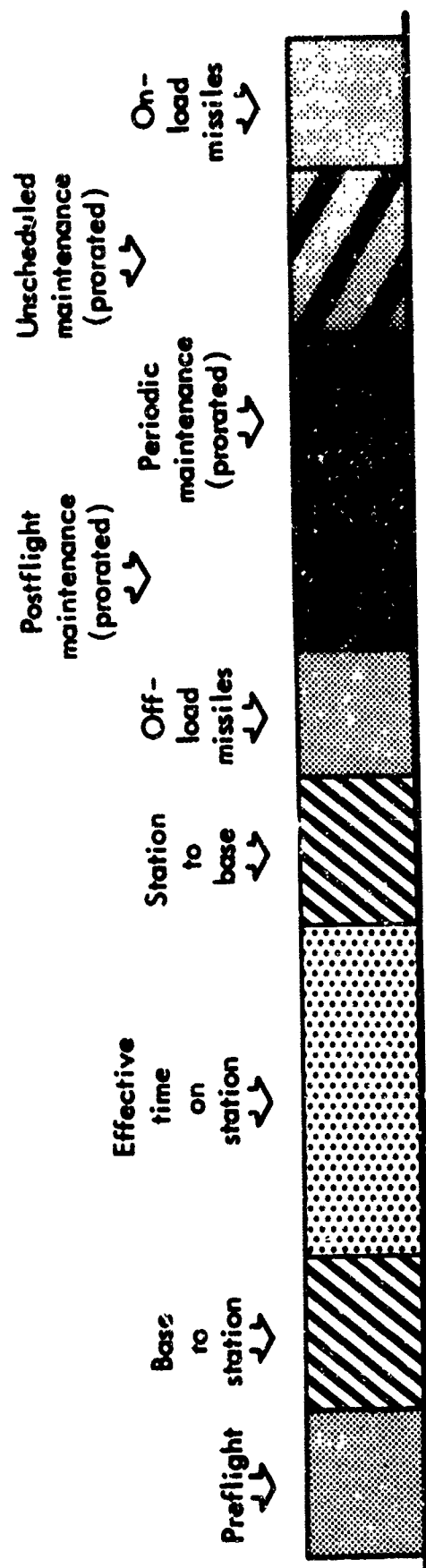
Having first chosen a weapons capability, our next task is to decide how this weapon will operate to perform our mission. We must then model or fully describe all the activities included in the performance of our mission so that we can prepare a list of all the resources required, and the costs.

If we limit our examination to the number of aircraft required for the time being, I think I can illustrate this modeling technique with the next chart.


Chart 5 shows aircraft cycle time in terms of the system activities that must be performed by or on each aircraft in the system. By "cycle time" I mean, of course, the time spent by an aircraft from the beginning of one mission to the beginning of the next. Part of the cycle time is spent in ground activity, which -- it should be noted -- contributes no useful input to our mission. But neither does all of the cycle time that the aircraft spends airborne. In fact, only the effective time on station can be considered as a useful mission input.


As can be seen, the remainder of the airborne time is consumed in transit and depends directly on the distance from base to station and the speed of the aircraft. Ground time is spent primarily in two kinds of activities: (1) on-loading, off-loading, and general preparation of the aircraft for its sortie, and (2) performing the required maintenance to ensure safety of flight. While we have discussed airborne time and ground time separately, it should be noted that they are significantly interrelated. The time required for maintenance depends on what needs to be done and the resources available for doing it. The amount of maintenance required per cycle is related to (1) the fact that there has been a sortie and (2) the number of hours flown.

Using this model of aircraft activities we can begin to investigate some aspects of our weapon system. We can see that the longer the effective time on-station becomes in relation to the total cycle time, the more efficient (and probably less costly) our weapon system would be.



 Flying time effective

 Flying time noneffective

 Ground time on a per sortie basis


 Ground time on a per flying hour basis

Chart 5—Aircraft cycle time

Aircraft endurance is the performance parameter which would have the greatest effect upon the ratio of effective time to cycle time. By endurance I mean number of hours which an aircraft could remain continuously aloft.

In Chart 6 the number of aircraft required to perform the 1000-mile area coverage mission is plotted against aircraft endurance. The most interesting aspect of the curve is that within the endurance range from 8 to 24 hours, the number of aircraft required by the system is extremely sensitive to even small changes in endurance. Beyond 24 hours this sensitivity is greatly reduced, as you can see by the flatness of that segment of the curve.

In Chart 7 we see the use of the same curve as in Chart 6 in order to relate ranges of endurance hours to aircraft type.

Circle 1 (8-18 hours) represents the current jet transport. Within this range slight changes in endurance have major effects on the number of aircraft required.

Circle 2 (18-40 hours) represents a small long-endurance aircraft (LEA) about the size of a C-135, designed for maximum endurance. It would require only a minimal R&D effort.

Circle 3 (40-60 hours) represents a large LEA, about twice the size of the small LEA. It, too, would require little state-of-the-art advancements in engine design or airframe fabrication.

Circle 4 (60-80 hours) represents an advanced LEA. It would be about the same size as the large LEA, but would require an extensive R&D program. Such an aircraft might include new regenerative turboprop engines and an airframe fabricated with laminar flow control devices.

From this chart one might conclude that the small LEA is an optimal choice for our defense mission. We shall examine and consider other factors affecting this choice later in the presentation.

Chart 8, which shows the number of aircraft once again as a function of endurance hours, attempts to illustrate the savings that a change in the maintenance policy might yield in reducing the number of aircraft required by the system. The curves that we have examined thus far were based on a single shift maintenance policy. Here we see the effect of going to a 2-shift or to a 3-shift or around-the-clock maintenance

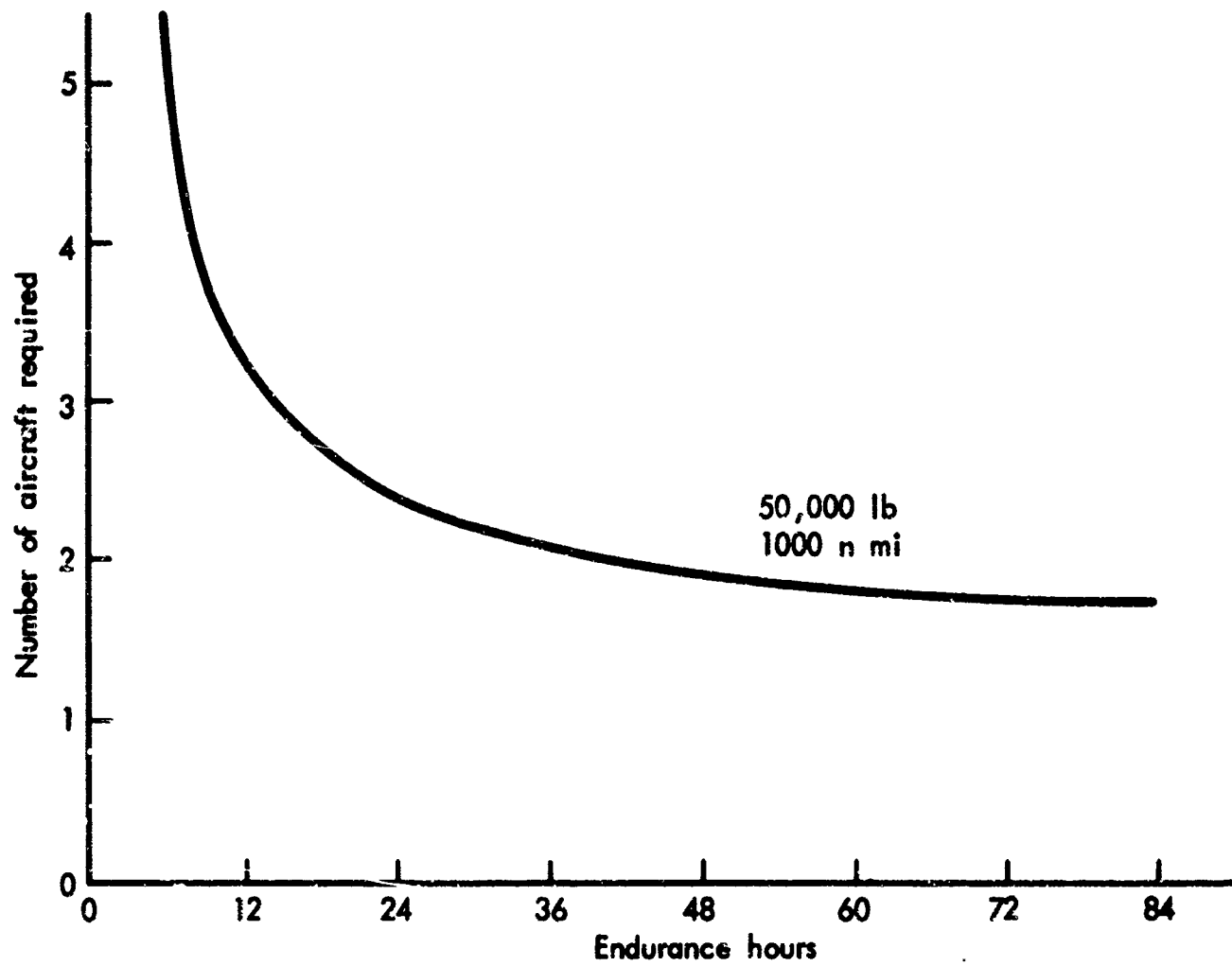


Chart 6—Number of aircraft versus endurance hours

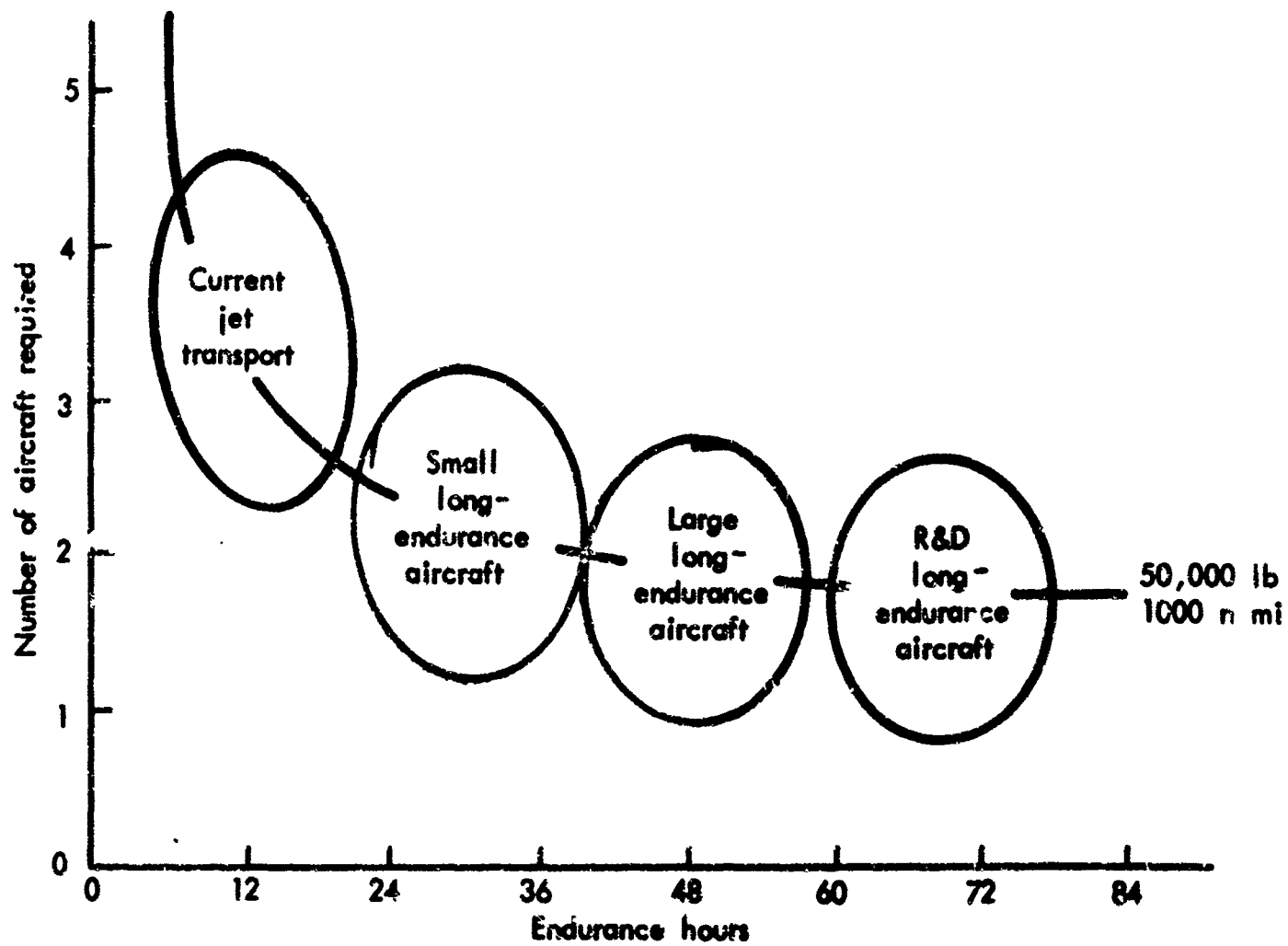


Chart 7—Number of aircraft versus endurance hours

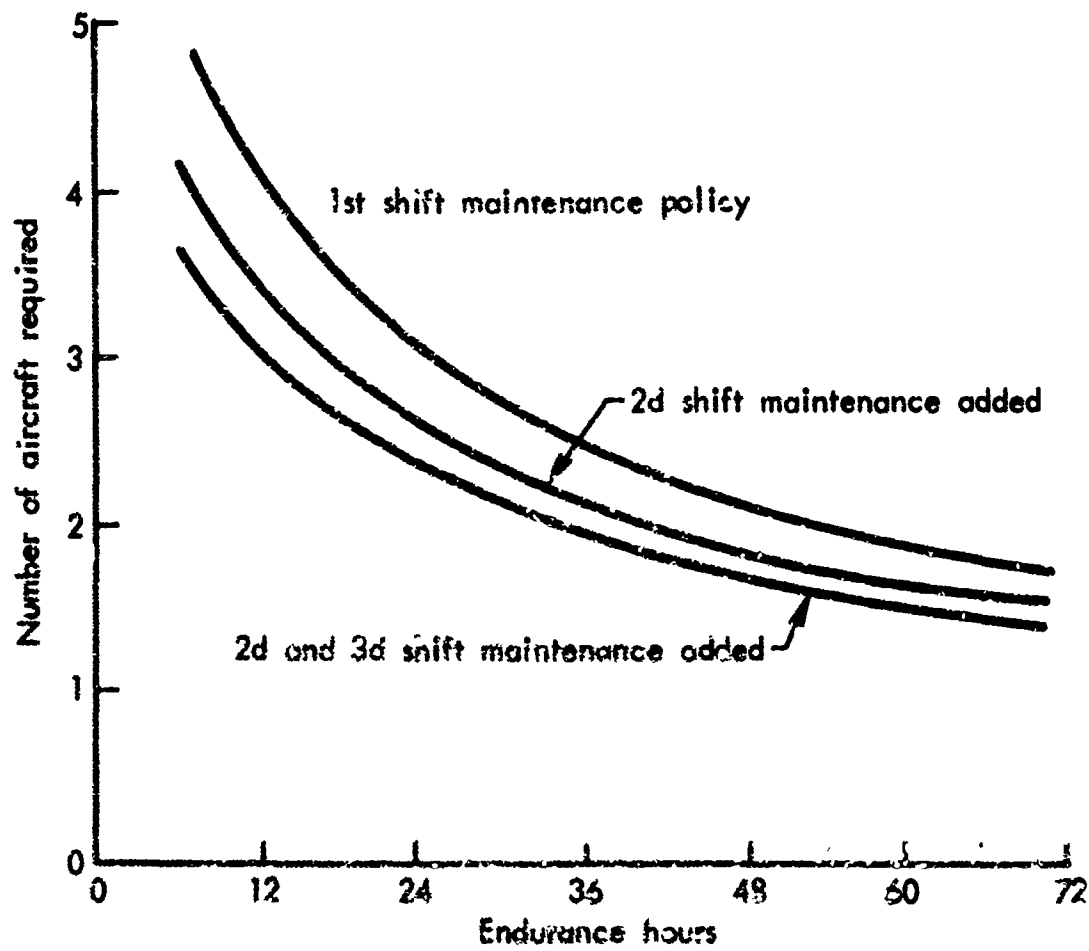


Chart 8—Number of aircraft versus endurance hours

policy. In absolute number of aircraft required, the greatest reductions resulting from the change in policy occur for the range of aircraft endurance from 8 to 18 hours. Beyond 18 hours the relative savings are essentially the same, but the absolute increment of aircraft saved becomes much less. As before, it appears that if we are in the position of having to rely on relatively short-endurance aircraft, the number of aircraft required is extremely sensitive to variation in some of the operational parameters. Chart 9 shows the percentage of the fleet airborne as a function of endurance hours. This is another way of representing the number of aircraft required by our weapon system. In this particular illustration, we have attempted to display the effect upon the number of aircraft required, of changes in the time per sortie devoted to on- and off-loading missiles. Where endurance is limited (8 to 18 hours), the savings that could be expected from reducing the time required to perform these operations are significant. As the endurance hours are increased, however, the value of the gains accruing to the system as a result of spending less time on these tasks is decreased.

In Chart 10 system costs are introduced for the first time. System costs are plotted against endurance hours in order to determine the effect on system costs of changes in the endurance of the specific aircraft under consideration for this mission. For this illustration total system costs are defined as the sum of the costs of research and development, initial investment and five years of operation. We can see that the shape of this curve is about the same as the curve in Chart 6 where the number of aircraft, rather than system cost, was plotted against endurance hours of the aircraft. Such similarity in the shape of the curves indicates that the number of aircraft and costs are directly related for each case considered in our illustration.

In Chart 11 we have added two additional curves to the one which appeared in Chart 10 -- bracketing the 1000-mile coverage curve with curves which represent the system cost estimates of reducing to a 500-mile or extending out to a 1500-mile defense zone coverage. As was mentioned at the very beginning, the decision to cover an area extending 1000 miles from each coast was an arbitrary one and was

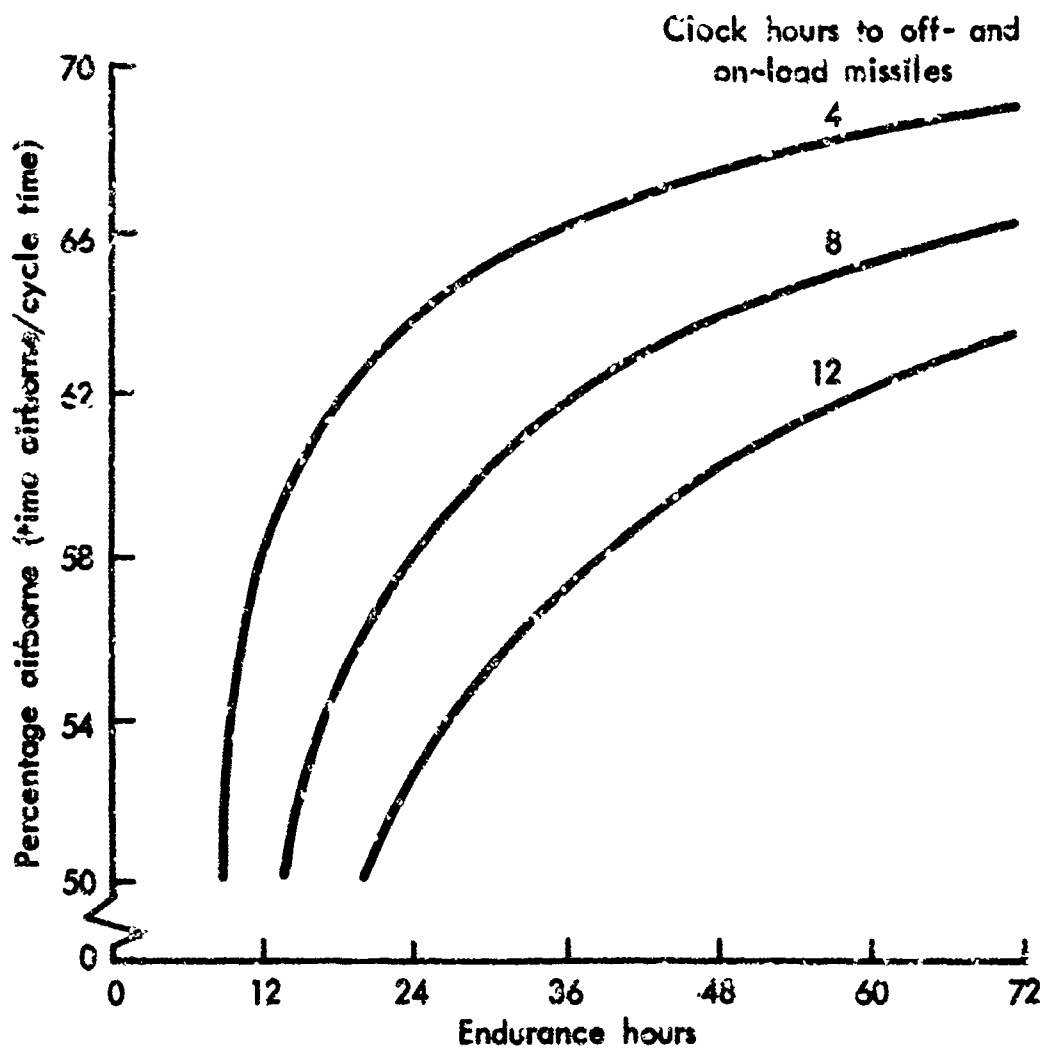


Chart 9--Per cent airborne versus endurance hours

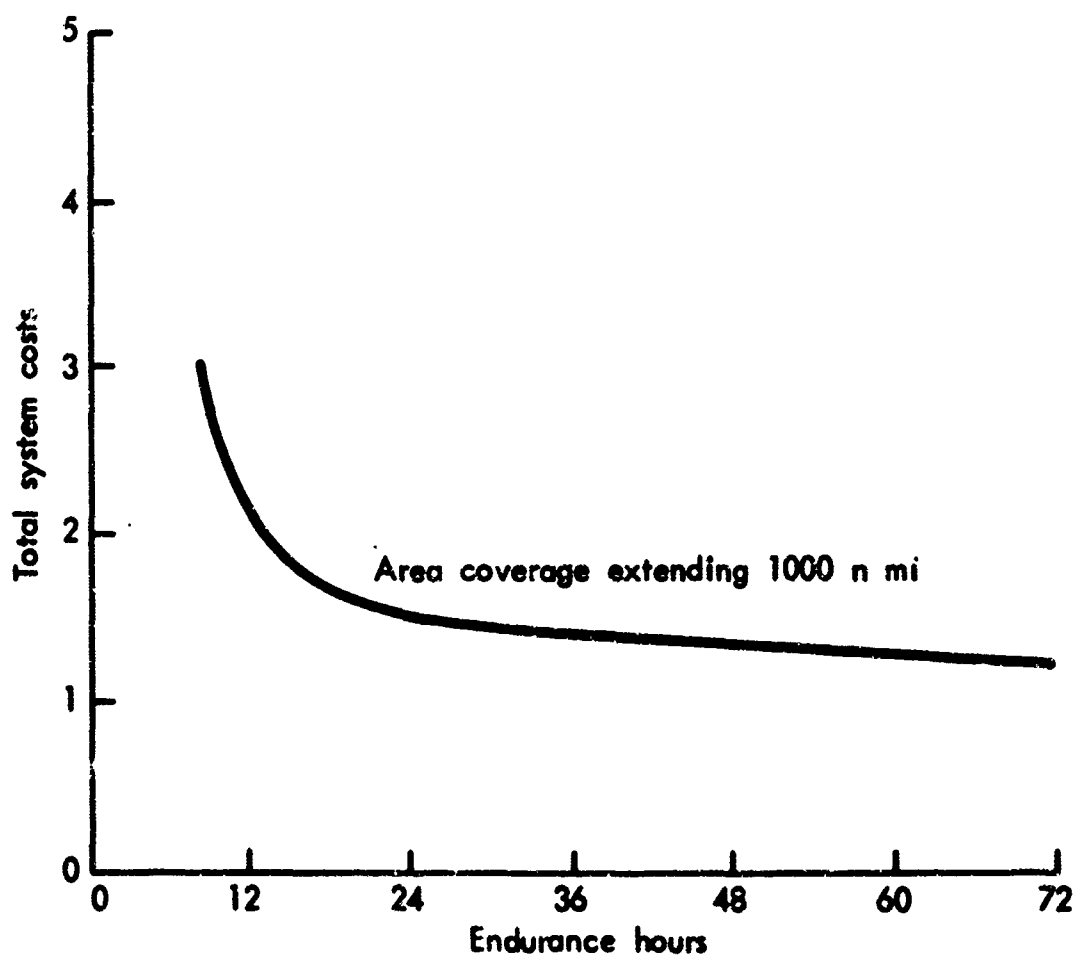


Chart 10—Cost versus endurance

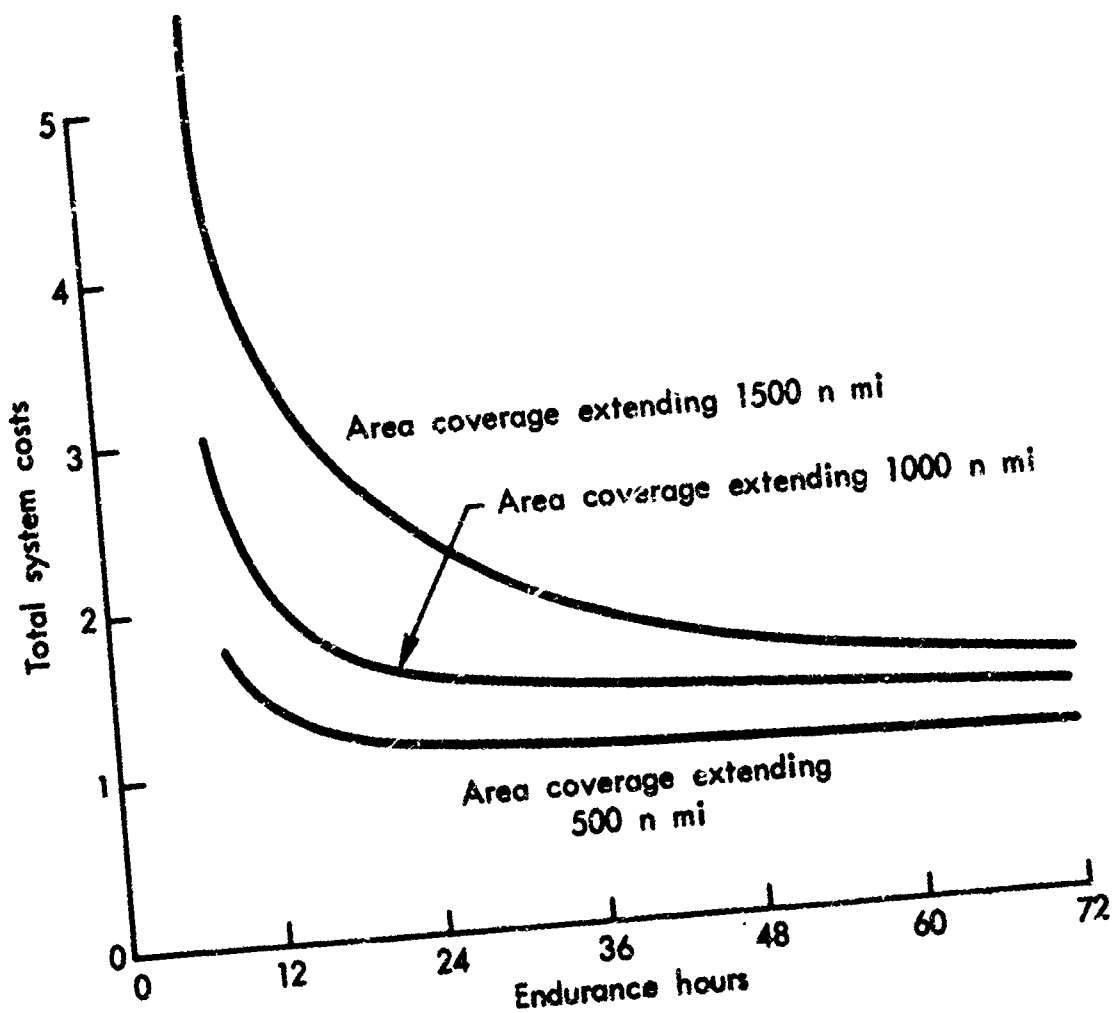


Chart 11—Cost versus endurance

related to an estimate of the range of the SLEM against which we might have to defend. We now want to indicate to the decisionmaker this is an area of uncertainty, and indicate the effect upon costs of this uncertainty. If, or when, we are faced with a threat greater than that implied by the 1000-mile coverage we see that an aircraft with greater endurance becomes even more attractive than we initially visualized. It can also be seen that as the range requirement is extended to 1500 miles, the curve becomes asymptotic to the vertical axis at about 10 hours. This means that for such 1500 mile coverage, an aircraft with only 10 hours' endurance would spend all of its time going to and from the patrol station, and could, therefore, contribute little to the performance of our mission.

Another major area of uncertainty which we can explore in our cost sensitivity analysis has to do with the deployment tactics available to our adversaries. We are uncertain as to our own submarine detection capability in distant time periods, and uncertain about the capability of our enemies to avoid or spoof our detection systems. If we were assured of a high probability of detection of the enemy's submarines, we could assume that he would be forced to disperse his submarine fleet. However, if we admit a very low probability of detection, we are forced to examine an enemy deployment which could include submarine wolf packs. In such a situation we may be forced to increase our defensive firepower per patrol station as much as three times more than originally expected. The effect of this kind of uncertainty is shown in Chart 12, which examines total system costs as a function of the size of the defense zone and presents the effect on the system cost of increased firepower requirements.

We not only explore the effect upon system cost of uncertainty regarding the threat, but also the effect upon system cost of possible state-of-the-art advancements in our own equipment design and development. This, too, can be illustrated by hypothesizing a possible growth version of our own terminal defense system (missiles and radars).

In Chart 13 we have presented the required number of aircraft on patrol as a function of the extent of the defense zone coverage. The upper curve, which is called "boost intercept coverage," represents the

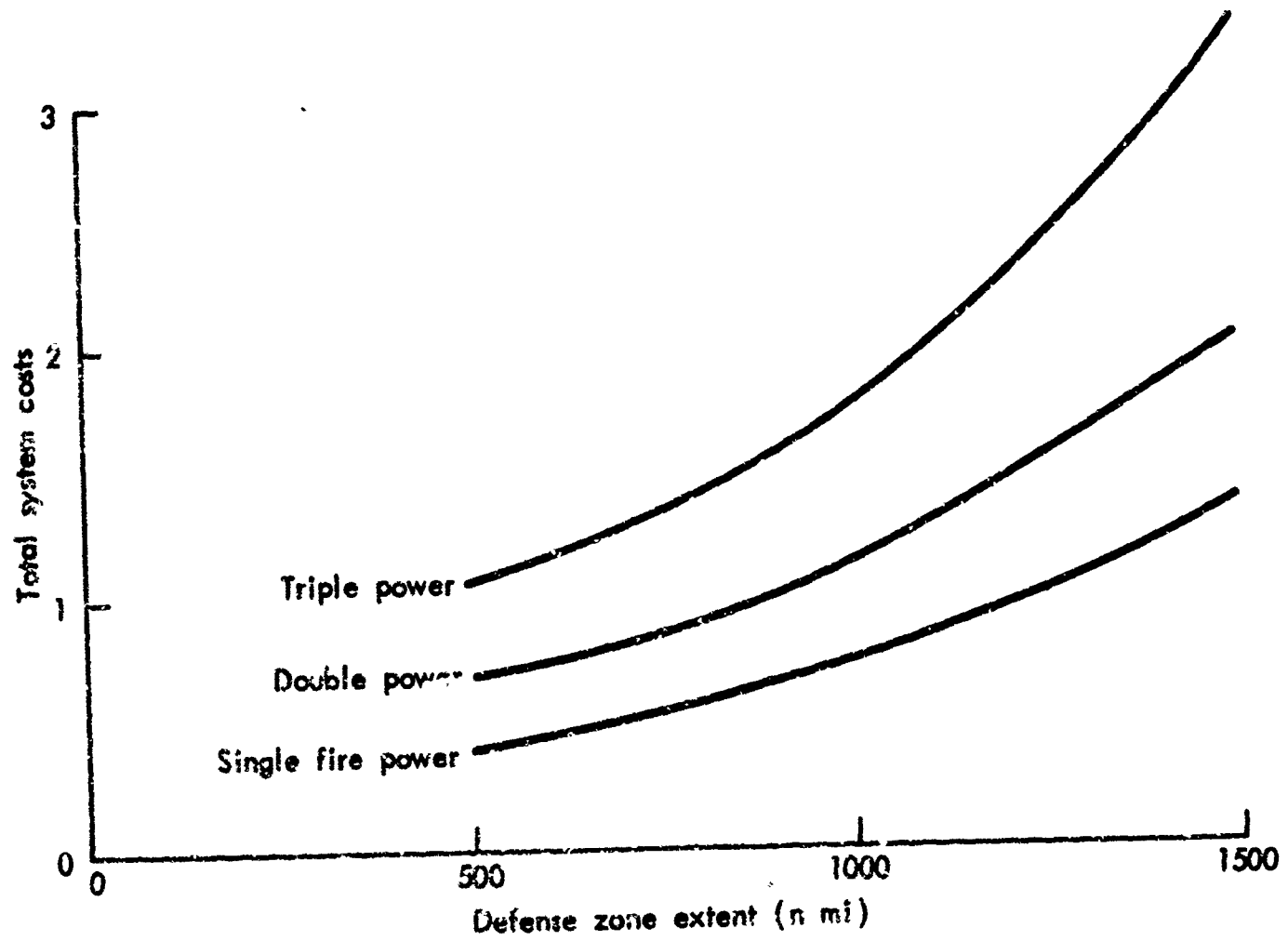


Chart 12—Cost versus defense zone extent

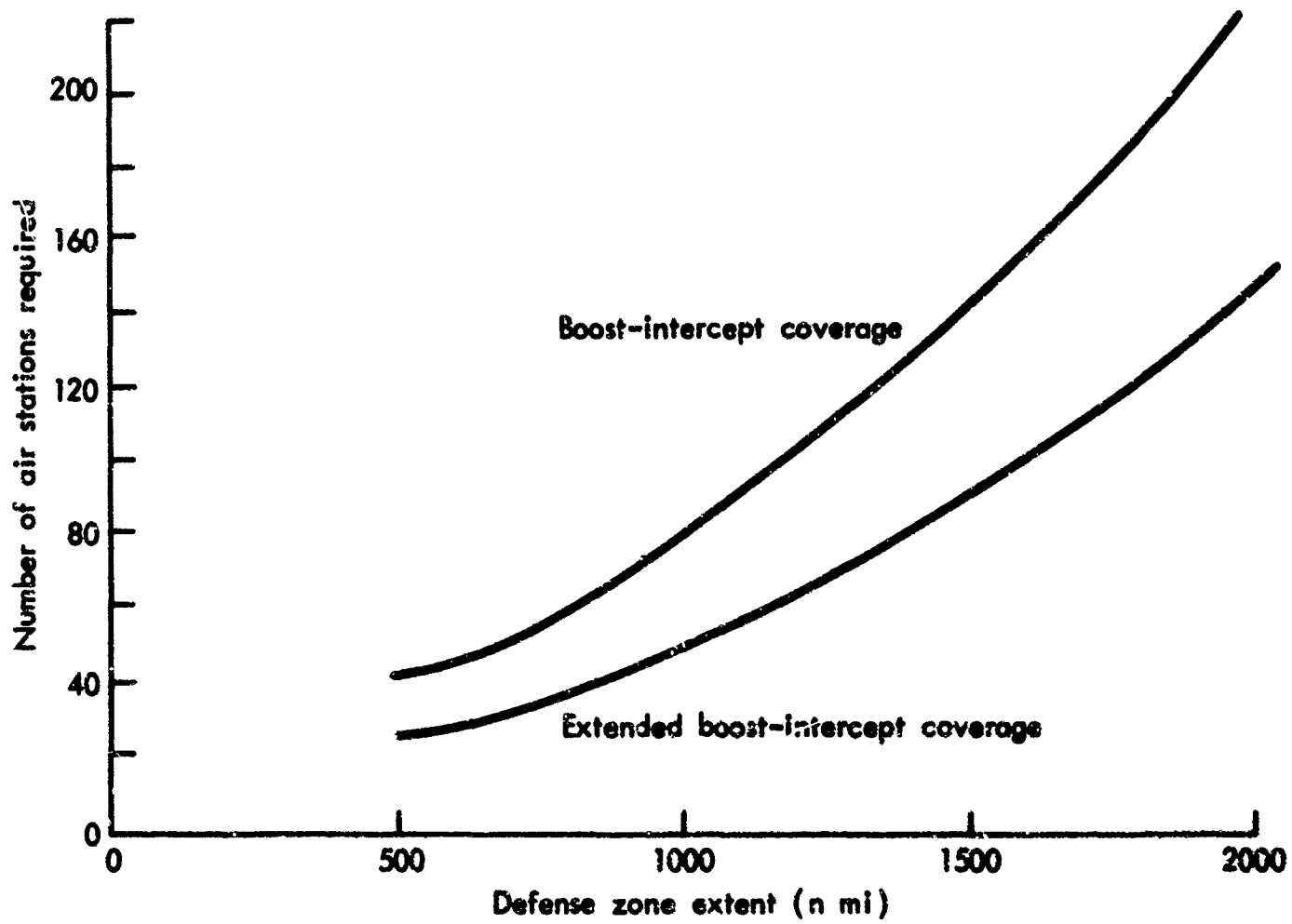


Chart 13--Number of air stations versus defense zone extent

capability of our system up to now, or our "A" model. The lower curve represents a new configuration identified as the extended boost intercept coverage and would be our follow-on system or "B" model. We can see that as the defense zone is increased beyond 1000 miles the new capability would substantially reduce the required number of aircraft on patrol and hence the system costs. Without even estimating the cost to develop, procure, or operate a weapon system with this new capability, we can still point out that technical research pointing to such a capability may offer a substantial economic payoff for our mission.

Chart 14 presents a somewhat different kind of sensitivity analysis. Here we see not total cost but cost per pound of payload on station as a function of total weight of the missiles carried by each aircraft on patrol. In this analysis we examine the effect upon cost when we trade off fuel for payload in each of the types of aircraft under consideration. When we look at the conventional jet aircraft we find that a 50,000-lb missile payload results in the lowest cost per pound on station. For the small long-endurance aircraft, the lowest cost per pound is achieved at about 75,000 lb, and for the large long-endurance aircraft it is achieved at about 125,000 lb of payload. What is of greater significance, however, is that the costs rise substantially for both the conventional jet and small long-endurance aircraft if we are forced to double the firepower. However, for the large long-endurance aircraft we can see a substantial area of insensitivity on a cost-per-pound basis to the payload weight requirement. Thus, a conclusion can be drawn that since there is much uncertainty with regard to firepower and coverage requirement, what we really require from our aircraft is flexibility. Flexibility can only be achieved by use of the large long-endurance aircraft for this mission. It is, of course, not suggested that the role of the cost analyst include making recommendations of a technical nature; however it is the cost analyst's responsibility to ascertain and analyze feasible equipment alternatives.

In addition to the variety of cost sensitivity analyses that have been presented so far, Chart 15 offers another kind which the decision maker may also find useful. It has to do with a parameter that has not yet been mentioned -- TIME, which for some plans may be the most

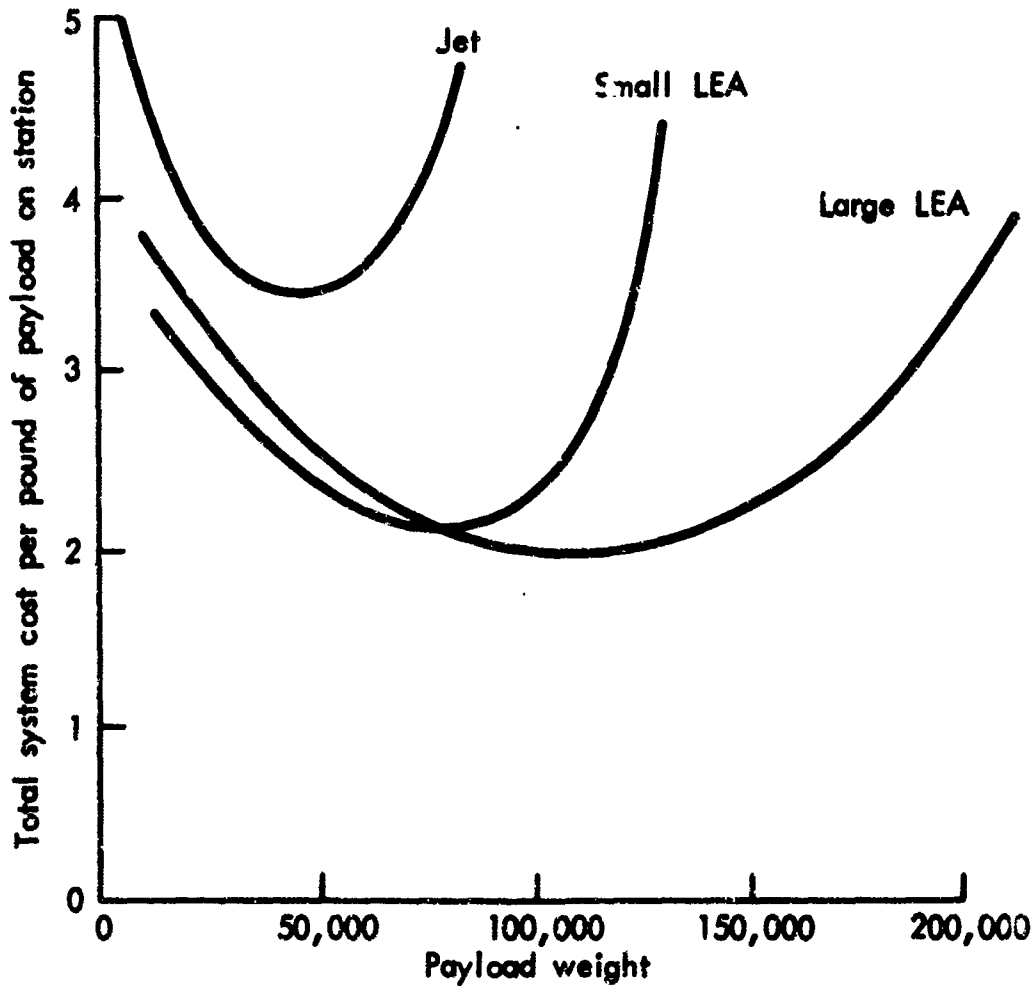


Chart 14—Cost per pound versus payload weight
(1000 n mi)

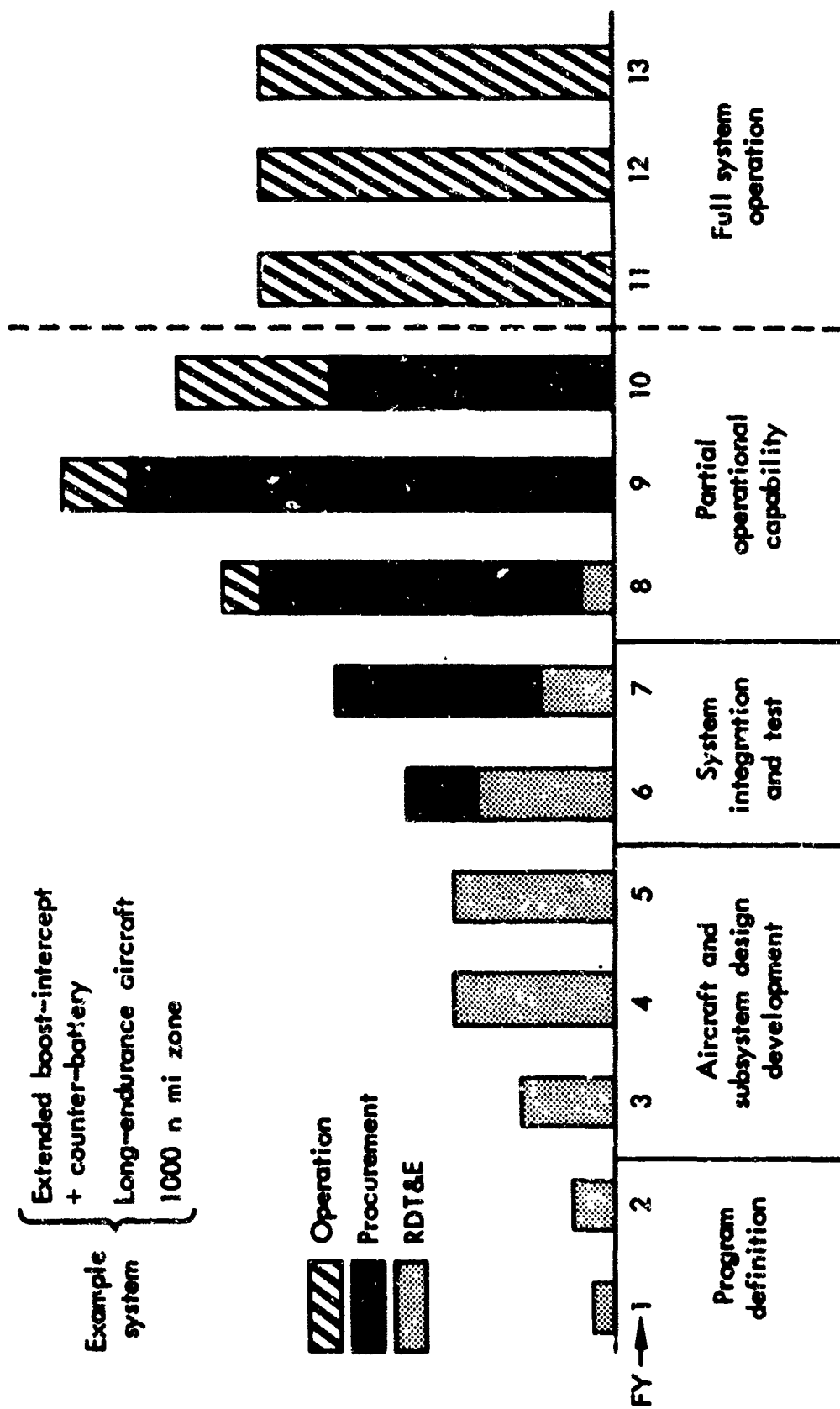


Chart 15—Time phased resource impact

critical factor. A military decisionmaker may not always be as concerned with total system costs as he is with costs over time. Not only does time affect the flow of costs, but it is also an important consideration in assessing the probable effectiveness of the new capability as it is phased into our operational forces. Note that after our decision to begin the definitional phase of our system, 8 years will have elapsed before we can expect it to be in full operation.

In conclusion, let me point out the major benefits which can result from use of cost sensitivity analysis. First, a cost analyst can point out where costs are relatively sensitive (or insensitive) to the value of particular parameters. Even more useful would be to point how within a particular range of values costs do not change significantly, while just beyond that range the costs rise sharply. This process can point out technical areas of potential high payoff in both equipment design and system operations.

Finally and most important, a cost analyst can provide, using sensitivity analysis, some quantitative values to the various forms of uncertainty with which he must constantly deal in preparing his cost estimate.